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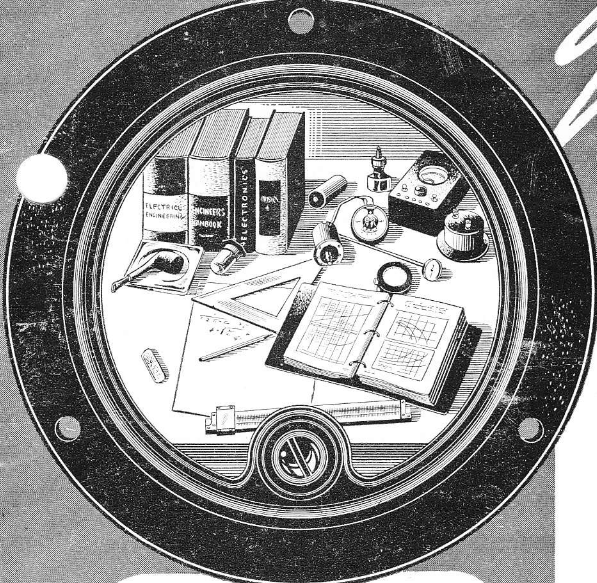

In This Issue

John Parker, Editor

A COMPLETE DIRECT READING Gm TUBE TESTER

TRANSCONDUCTANCE as applied to an electron tube can best be defined as the ratio of the change in the current in the circuit of an electrode to the change in the voltage on another electrode, under the condition that all other voltages remain unchanged. As most precisely used, the term refers to infinitesimal changes. Since the input-output relationship is most important, the grid-plate transconductance or the mutual conductance of a vacuum tube is the parameter that the engineer is most frequently interested in studying

Theory and Method

If d-c potentials are applied to all tube electrodes with the possible exception of the heater, then an a-c signal of definite value can be injected into the control grid circuit, and the mutual conductance measured on a calibrated milliammeter in the plate circuit reading a-c only. The relation between control grid signal voltage and the alternating plate current resulting therefrom may be expressed by the equation:

$$i_p = \frac{\mu e_g}{R_p + r} \qquad (1)$$

where:

e_g = *injected signal voltage*
i_p = *resultant a-c plate current*
μ = *amplification factor*
R_p = *tube impedance*
r = *tube tester plate circuit impedance including instrument resistance.*

By dividing numerator and denominator by μ the equation becomes:

$$i_p = \frac{e_g}{\frac{R_p}{\mu} + \frac{r}{\mu}}. \qquad (2)$$

It is known that

$$\frac{\mu}{R_p} = g_m. \qquad (3)$$

Therefore, by substitution

$$i_p = \frac{e_g}{\frac{1}{g_m} + \frac{r}{\mu}}. \qquad (4)$$

If we could obtain in practice the ideal condition where r was equal to zero, then the simple relation would exist:

$$g_m = \frac{i_p}{e_g}. \qquad (5)$$

In actual practice, this simple relationship does not obtain since the measuring instrument which is inserted in the plate circuit to measure the value of i_p necessarily introduces a finite impedance or external plate circuit resistance r. With some types of tubes and for some purposes, sufficient accuracy is obtained when it is assumed that the external resistance r is so small in comparison with R_p that it may be ignored. This applies in the case of high plate resistance or high μ tubes. However, in the case of low plate resistance tubes such as conventional low μ triodes, the factor r is a part of the total plate impedance which cannot be ignored.

The Gm Meter

To determine the calibration of the g_m meter on its lowest range, the impedance of the instrument and its associated network must be determined. This value plus the power supply impedance may

WESTON ELECTRICAL INSTRUMENT CORP.,
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be designated r_o, and the lowest required value of amplification factor μ_o. The meter may then be calibrated in micromhos from the equation:

$$i_p = \frac{e_g}{\dfrac{1}{g_m} + \dfrac{r_o}{\mu_o}}. \qquad (6)$$

This calibration will hold true for one value of μ, that is, μ_o.

However, if the condition:

$$\frac{r}{\mu} = K \ or, \ r = r_o \frac{\mu}{\mu_o} \qquad (7)$$

is maintained, then the above calibration would hold for all values of μ. This condition can be met by adding resistance values figured from equation (7) to the meter resistance by means of a tap switch marked off in amplification factor steps. This method is disclosed in patent number 1,854,901 issued to W. N. Goodwin, Jr., and assigned to Weston.

The above method is used in the calibration of the Weston Model 686, Type 9, Mutual Conductance Tube Tester, shown in Figure 1. This model was first produced in 1935 to meet Navy requirements for a flexible direct reading mutual conductance tube tester to be used on shipboard or at Navy bases and laboratories. The new commercial Type 9 is now in production. This type has several interesting features, some of them new and some carried over from previous types.

Gm Ranges

Three mutual conductance ranges are available: 3000, 6000 and 15,000 micromhos full scale. The meter scale has two arcs, one in black and one in red. The black arc is used for tubes with listed amplification factors of 20 or lower. The switch to the left of the g_m meter is set to the nearest value of μ, selecting the correct resistance value as calculated from equation (7). The red arc applies to g_m measurements on tubes with an amplification factor above 20. The last position on the amp factor switch is marked "Red Scale", and is used on all types having a μ of over 20. Here the g_m meter operates as a simple milliammeter since the meter resistance becomes so small in relation to tube resistance that the term r in equation (4) may be neglected and the conditions of equation (5) obtain.

The signal voltage is injected into the control grid circuit by operating a momentary switch, (lower right of Figure 1). The signal potentials are 1 volt, .5 volt and .2 volt at power line frequency, on the 3, 6 and 15 thousand micromho ranges respectively. Thus, high g_m, low bias tubes such as the 6J4 or 6J6 can be measured with peak signal voltage well below the normal grid bias voltage.

Top Panel Section

There are two panel sections, with all sockets and interelectrode short test switching confined to the top or small panel. The six instruments with associated multipliers, switches, power supplies and controls make up the main or large panel section. The sockets may be easily removed for alteration should new mechanical socket designs appear, or a new panel could be made available should extensive mechanical changes be required. Since all instruments read in fundamental units and are mounted in the lower section, this model should see many years of service before it would be considered obsolete. Patch cords are used for all electrode connections. This patch cord system, although seemingly slower in operation than switching, has proven well worthwhile throughout the years. Two and three section tubes can be measured with individual or parallel tests, cross ties between electrodes can be patched, or emission readings taken on groups of electrodes. Storage jacks for the patch cords are available on the top panel. The standard R.M.A. numbering system is used for all base connections.

Either hot or cold short tests can be made before proceeding with the test procedure. A top panel rotary switch automatically segregates each electrode, and a neon lamp indicates the short to any other electrode. The filament jacks only are patched for the hot short test.

The Five Electrode Meters

A two-range microammeter for grid current readings appears to the left of the fan shaped g_m meter. This has a fundamental range of 15-0-15 microamperes. It is normally shunted to 1500-0-1500 microamperes, and is operative on the low range by manipulation of a momentary switch. This is a zero center instrument to indicate any or all components of grid current resulting from gas, leakage resistance or secondary emission. Grid current readings are especially important in segregating defective power tubes such as the type 6L6, where a limit of 3 microamperes is specified.

A 4-range milliammeter is mounted to the right of the g_m meter, operating in conjunction with a range switch and an electrode switch. By manipulating the latter, this meter will read d-c current in the plate, screen, and anode grid or cathode circuit of the tube under test.

The two-range electrode voltmeter will be noted directly below the milliammeter. This reads plate, screen or second anode potential as required, by switch manipulation. A red arc on the scale plate indicates voltmeter current which can be subtracted from low range milliammeter readings where this current may be an appreciable part of the total.

The double range control grid voltmeter mounted directly below the grid microammeter, is used for adjusting grid bias potential. The range switch also changes the potential across the control grid potentiometer so that the voltage increment per degree rotation is approximately the same on each range.

Filament potentials from 1 to 120 volts are available through a rotary switch and a voltage control. The switch selects the nom-

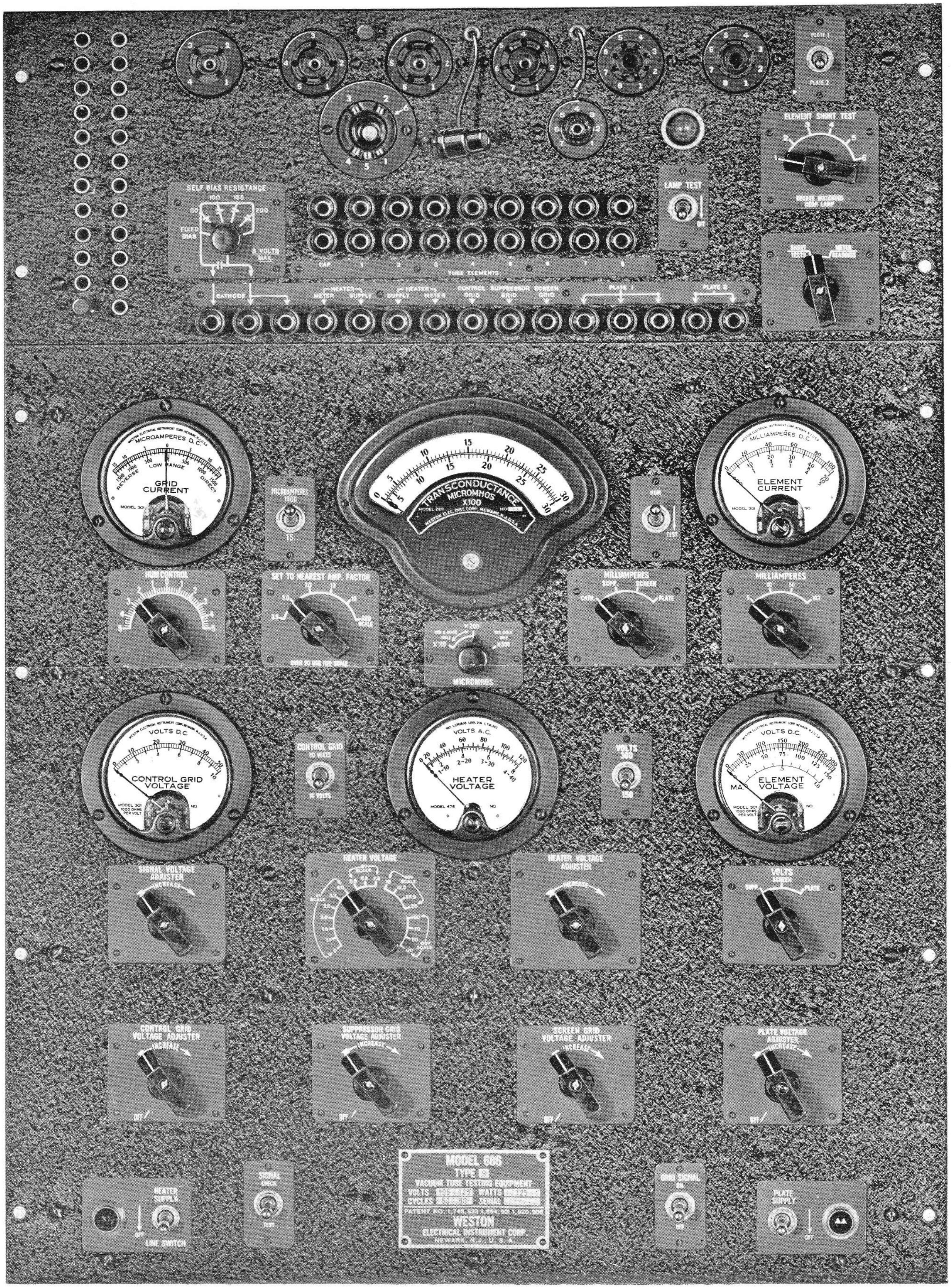


Figure 1—Head-on view of the Weston Model 686, Type 9 Mutual Conductance Tube Tester. Actual dimensions 19 x 26 x 7.3 inches.

inal voltage, and exact adjustment is made by controlling the filament transformer primary potential with the potentiometer setting. An interlock circuit is used on the rotary switch to automatically shift ranges on the filament voltmeter as the switch is rotated. Thus the operator always has this meter on the correct range, and the possibility of instrument overload is considerably reduced. The voltmeter connections are brought back through separate leads directly from the tube socket thus providing a more accurate reading of filament potential at the tube pins. The meter has ranges of 4, 8, 40 and 120 volts full scale.

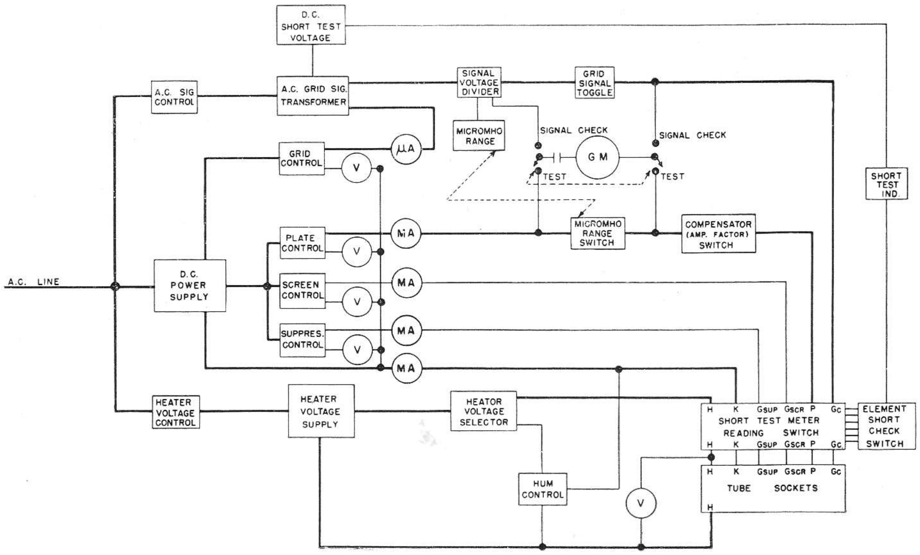


Figure 2—The flexibility and scope of the Model 686, Type 9 is clearly shown in this schematic block diagram.

The Controls

Individual plate, screen, anode grid and control grid potentiometers are mounted in line across the lower section of the Model 686. These are 150 watt or 100 watt vitreous type potentiometers connected in the d-c supply circuit. While these high wattage ratings are not required, controls of this size are used to provide a long peripheral length of contact travel and thus render more accurate potential settings on the tube electrodes.

The signal voltage adjuster controls the a-c current through a series of accurately adjusted resistors developing the signal potential for each g_m range. To eliminate possible temperature errors in the rectifier g_m meter, the signal potential is checked against full scale deflection on the g_m meter, and any required correction made with this control. Should any serious error in signal potential or meter sensitivity occur, this would be apparent when the "Signal Check" switch is operated.

All directly heated or filament type tubes are measured with a center tap return connection. A low resistance potentiometer marked "Hum Control" is switched across the filament leads on the low ranges up to and including 10 volts. This control is used to locate the exact electrical center on filament tubes, and thus eliminate errors on the g_m meter caused by an unbalanced grid circuit return.

Self Bias Switch

The new Type 9 model is equipped with a self bias switch mounted in the top panel section. This has been added for certain tube types such as the 6J4, 6J6 and 1231 where self bias is definitely specified by the manufacturer. These tubes tend to draw grid current under equivalent fixed bias conditions, wherein errors in g_m readings would be encountered.

The switch is wired for 50, 100, 150 and 200 ohm positions, with one spare position, now shorted, and one marked "Fixed Bias", which is a short circuit position. Since the circuit includes a low voltage 1000 microfarad by-pass condenser, this switch does not open circuit on any position, and it must be indexed to the "Fixed Bias" position for measurements on all types except those where self bias is specified.

Separate power switches are available for heater supply, and plate-screen-control grid potentials. Thus a tube to be tested may be heated while the operator is manipulating the other controls. A block diagram is shown in Figure 2 instead of a wiring diagram. It gives the reader a much clearer idea of the flexibility and scope of the device, than would be possible with a complete wiring diagram. A rear view of the Model 686 with back cover removed is shown in Figure 3.

Increased accuracy on power tube measurements is noticeable in the Type 9. This has resulted

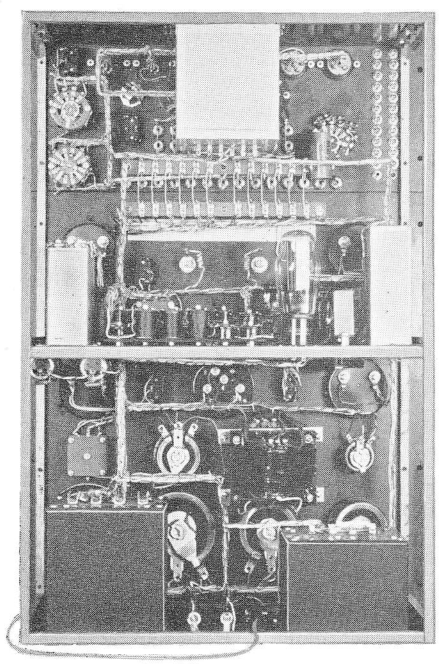


Figure 3—A rear view of the Model 686 showing back cover removed.

from a study of degenerative effects in previous types. Several changes have been made in the components to evolve this improvement, and every effort has

been made to make this an accurate device. Comparative g_m readings are taken continually on Weston's standard mutual conductance tester, truly a laboratory device weighing about 500 lbs. This is shown in Figure 4. Here instruments accurate to within $\frac{1}{4}$ of 1% are used, electrically equivalent to the Weston Model 1, but in magnetically shielded cases. Tubes as they are announced are carefully calibrated on this equipment and recorded for use in adjusting and checking both emission and mutual conductance tube testers.

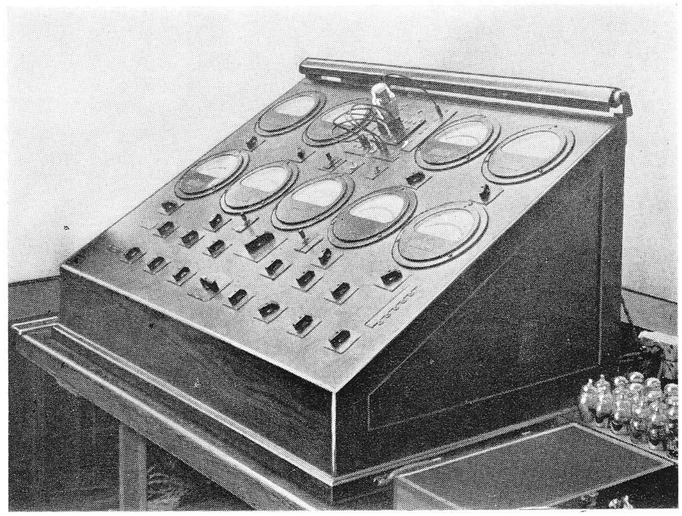


Figure 4—Comparative Gm Readings and recording data on new tubes keep this Standard Mutual Conductance Tester in use constantly.

Non-ferrous metals are used in all parts of the Model 686, with the exception of instrument magnets and transformer cores. This is a carry over from Navy requirements, but seems well worthwhile where long life is expected. Many of the forerunners of this type have seen ten years of shipboard service and are in active use today.

The Model 686, Type 9 Mutual Conductance Tube Tester lists at \$835.00, and will shortly be a stock item.

E. N.—No. 12 —*O. J. Morelock*

DIFFERENTIAL INSTRUMENTS AND RELAYS

FROM time to time special requests come to the Weston Corporation for differential relays and instruments of various kinds and it is felt that a discussion of the several methods of securing differential action might be of interest since some methods result in much more complicated assemblies than others.

The question is frequently asked as to whether or not we make a true two-coil, four-spring differential type of indicating instrument or relay and the simple answer is that such instruments and relays are made. However, differential instruments of this type require four springs for an indicating instrument and five for a relay and the piling up and insulating of the several springs on the pivot bases of the moving element lead to complex assembly requirements which make such an assembly most difficult and very expensive.

It is suggested that the following differential circuits be considered as possible substitutes for differential instruments or relays with independent coils to determine if one of them may be satisfactory for the proposed application. If so, time and money will surely be saved and greater simplicity will be achieved.

As a starting point, consider

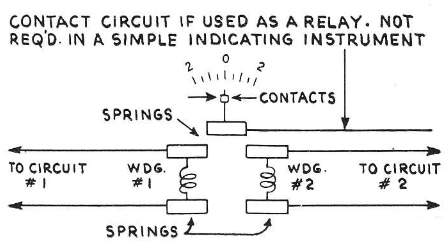


Figure 1—Schematic Diagram of the orthodox Two-Coil System.

the orthodox differential two-coil system as shown schematically in Figure 1. This arrangement, while it can be built and has been built in certain models, is not a desirable production item, and from the users' standpoint it is complicated due to the multiplicity of springs and terminals. Sensitivity is sacrificed in that the two windings actually are each less than one-half winding, since the two windings and the separating insulation must still fit in the same air gap normally occupied by only one winding.

Note that each of the windings requires two control springs to carry the current in and out of the winding. Thus, four springs are required for the windings and an additional spring is required in a relay for the movable contact arm. Thus a total of five springs would be required in such a relay and it must be noted that each spring will be more fragile than if only two or three springs were needed since the total torque would be the same.

Standard single coil instruments carry two springs and similar relays a maximum of only three

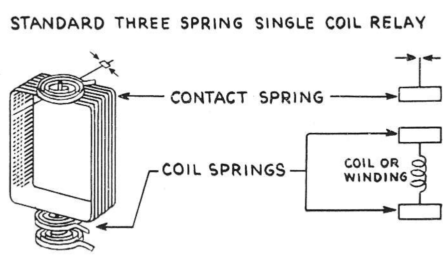


Figure 2—Diagram showing Standard Single Coil Three-Spring Relay.

springs as shown in Figure 2, and while a special instrument or relay and the enclosing housing large enough to contain three

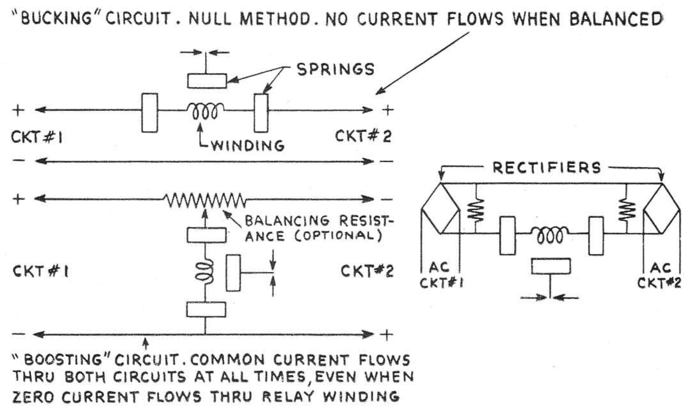


Figure 3—Elementary circuit diagrams showing a few simple arrangements used to obtain operating equivalents of a true differential device.

springs could theoretically be built, from the practical and economical viewpoint it would not be feasible to do so unless very large quantities were involved. However, many hundreds of differential instruments and relays have been supplied having either a regular single winding or a single winding tapped at the midpoint, or elsewhere, and the associated input circuits to these devices have been so arranged that differential action is secured.

The several circuits in Figure 3, while very elementary, show some of the simple arrangements which may be used to obtain operating equivalents of a true differential device. In general, the idea is to arrange the external circuit so that it accomplishes the differential action and feeds the result to the standard single coil relay or instrument. This usually involves connecting the two input circuits together at some point, through limiting resistors, capacitors, or rectifiers as required by the particular application.

These arrangements require that circuits #1 and #2 be tied together directly or through circuit elements at two points and at intervals of unbalance or possibly at all times there is some interchange of current between the circuits. The magnitude of this current is usually of the order of microamperes and in most cases does not upset either circuit too noticeably. However, the interchange of current does take place.

Where such interchange of current is prohibited or for some other reason the dual tie-in is objectionable, a hybrid tapped coil which still permits the use of the three-spring combination is possible in an instrument or a relay and is still preferable to the very special two-coil insulated assembly. To accomplish this result it is necessary that the winding be tapped, not necessarily in the center, but between any two layers (some coils have ten or more layers) and that the tap be connected to the spring which normally handles only the contact circuit in the case of a relay. Thus the two circuits are tied together at only one point and have only the resistance of the spring as a common resistance. Spring resistance is generally of the order of one ohm and may usually be disregarded as a common factor. In the case of the relay, one contact circuit may also be connected to this middle or common spring although this involves tying the relay contact circuit in with the actuating network. Such a three-spring relay is shown in Figure 4. If the circuits permit this arrangement, it affords differential operation without material interchange of current between circuits #1 and #2.

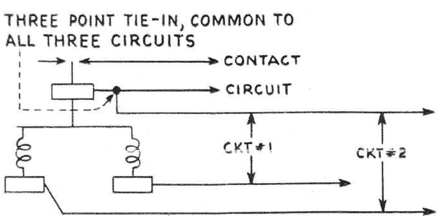


Figure 4—Diagram of a Three-Spring Relay.

This type of circuit has been used to add or subtract two currents or two voltages and to add or subtract a current and a voltage, with or without shunts as required, and to operate a pointer or a contact. It has been used to indicate a balanced condition with equal currents or voltages in the two circuits or when some very definite difference exists between them. In general, many special types of action and sequences of relay performance can be used by this method other than and beyond the differential action referred to in all of the foregoing.

In relays, non-differential uses consist of such things as using only one section of the winding for measuring purposes and the other section to feed back or superimpose a current which aids or opposes the rotational movement caused by the current in the measuring section. This feature is

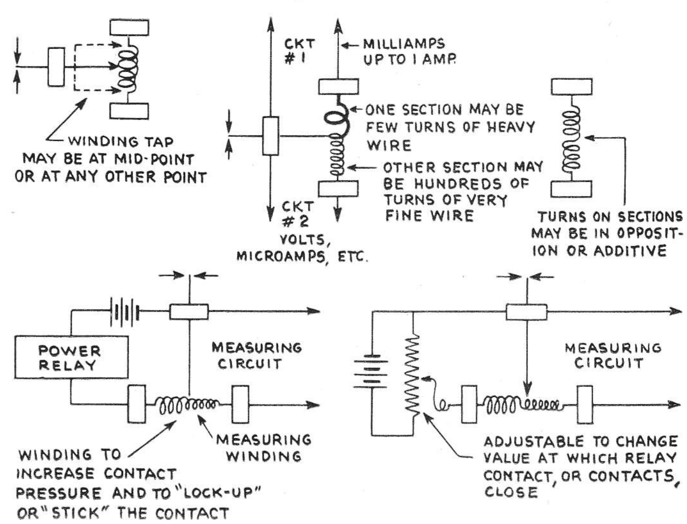


Figure 5—Diagram showing a few of the non-differential uses in Relays.

widely used to increase contact pressure at the time a very sensitive contact just starts to close electrically. Current from a battery flows through the non-measuring section to increase the pressure by thousands of times that which could be obtained by the current flowing through the measuring section alone.

Another use is to feed just a small current through the non-measuring winding so that a larger than normal difference is obtained between "make" and "break." One more use is to pass, by manual rheostat, any desired value through the second section of the winding so that by this means the relay is "adjusted" or "set" at will to operate at any desired value, and quickly changeable without opening the cover to change contact settings. Many more out of the ordinary uses have been made and are possible. Several of the arrangements mentioned are sketched in Figure 5.

While the three-spring circuit diagrams of Figure 5 are drawn around relay applications using a tapped moving coil, it might be noted here that one of the simpler methods for obtaining differential action in either an instrument or a relay is the shunt method shown in Figure 6. Here a standard two-spring moving coil is provided with a center tapped shunt resistor. This introduces a moderate amount of extra resistance into the measuring circuit but effectively the arrangement is

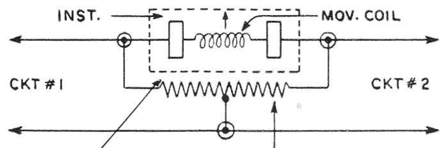


Figure 6—Diagram showing a standard two-spring moving coil provided with a center tapped shunt resistor.

equivalent to the tapped moving coil except for the additional common resistance in the network. The value of the shunt depends upon the current sensitivity required and the other factors of allowable resistance. This type of instrument is widely used in telegraph circuits as a differential milliammeter for making adjustments in duplex and quadruplex circuits.

This discussion has considered both instruments and relays for the reason that relay applications for the control of phenomena which can be handled electrically appear to be increasing in importance.

As a perfectly practical matter, it is well nigh impossible to include in a discussion of this sort all of the possibilities since they involve all possible networks. For example, there have been made so-called duplex differential instruments with two independent coils and four springs, and with each coil shunted with a center tapped resistor to give six binding posts and a true double differential action.

Possibly all of this goes to show that the possibilities of instrument construction and use with special networks is an art in itself, hardly one which can be learned but rather one which is a result of having explored a very large number of such requirements to the building of a background indicating the various general methods. It is urged that problems of this sort be presented to us in their entirety rather than as a request for a specific relay arrangement since it is frequently possible to abstract from our background an equivalent but simpler way to arrive at the required results.

E. N.—No. 13 —*Anthony H. Lamb*

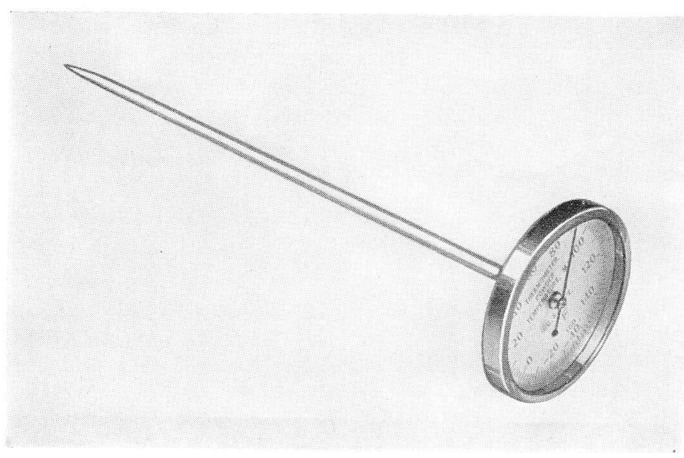
GUNS AIMED WITH THE AID OF THERMOMETERS

LARGE quantities of Weston Spiked Stem Testing Thermometers went to war with Uncle Sam's gun crews. The War Department called them "Thermometer, Powder Temperature, M1".

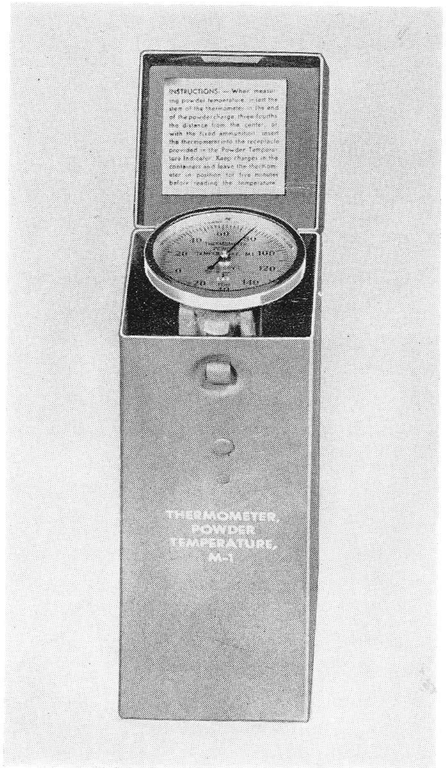
These thermometers were used for taking temperature measurements of powder charges (in sacks or bags), and of fixed ammunition (loaded shells). They were standard fire control equipment for all guns and howitzers of 105 MM caliber and larger.

Naturally, one of the most important things to be taken into consideration during an artillery duel or during any shelling of enemy positions, is the effectiveness or accuracy of the firing. Missing the target is often worse than holding fire, since retaliation by the enemy is to be expected.

In aiming large guns, after



The Weston All Metal Spiked Stem Powder Thermometer.



The metal container shown above was designed specially for the Armed Forces to house the Weston Powder Thermometer.

making all the usual observations, computations, and adjustments, the target might still be missed by a mile if allowance isn't made for the temperature of the powder (the propelling powder charge, not the blasting powder in the war head).

Firing tables are based on a powder temperature of 75°F and allowance must be made for even a few degrees deviation. The potential and burning rate of powder increases as the temperature rises, giving greater muzzle velocity and increased travel distance. If the powder is warmer than 75°F and proper allowance is neglected the projectile overshoots the target; if the temperature is a few degrees lower and goes undetected the shell falls short, possibly on our own forces.

To determine the correct temperature of the powder the bagged charges are kept in their containers and the spiked stem of the thermometer is jabbed right through into the powder. The temperature reading is then checked against a tabulation of the effects of variations from standard temperature thus enabling the gun crew to make the necessary corrections in the firing data.

In the case of the preloaded shells the temperature is measured by inserting the same thermometer in a hole positioned so the stem comes in contact with the powder charge. In this instance only a certain percentage check is made and the sampling shells with the special hole are known as Powder Temperature Indicator Shells.

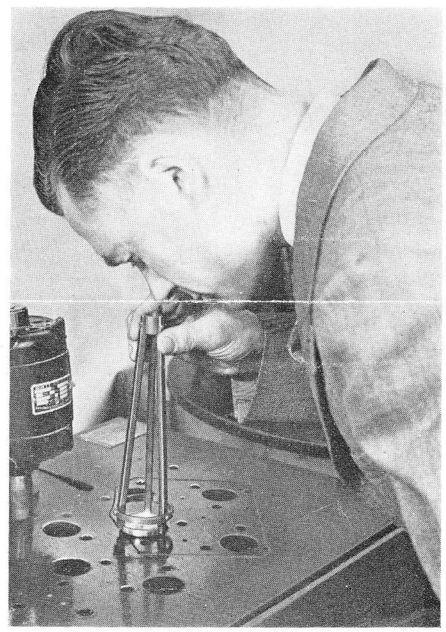
The importance of having the powder and ammunition in perfect order, and of having the proper instruments and means of getting the most out of it, is obvious. In this particular application the overall results obtained are no better than the precautions taken to achieve perfect aim and in the extreme temperatures of battle the aim is no better than the thermometer.

Even though the crew and their equipment and supplies reach the battle line in excellent condition, inability to check powder temperature changes and make the necessary adjustments could mean the failure of a firing mission. Therefore, it was important that a good thermometer be used and that it be reliable and of unquestioned accuracy even under the abuse and shock and lack of attention frequently experienced in the heat of battle and in wartime transportation from battlefield to battlefield.

In a large measure, therefore, the final effectiveness of the explosives and ammunition may depend on the thermometer, and the skill, care and material which went into the design and manufacture of the thermometer.

In making and checking these thermometers we kept in mind constantly the adverse conditions under which they would frequently be used, and we subjected each one to almost ruinous tests; they were shocked, submerged, frozen and overheated; then they were checked. Over their entire range of $-40°$ to $+160°$F they were all accurate to within 1°F ($\frac{1}{2}$ of 1% of full scale).

As these Weston All Metal Spiked Stem Powder Thermometers flowed out of our plant on their way to War we felt secure in the knowledge that not one more test or care could be given them to make them more suitable for their intended purpose.



After being subjected to numerous tests each thermometer was carefully inspected.

E. N.—No. 14 —*Anthony H. Lamb*

Ref: "Ordnance Standard Inspection Procedure for Thermometer, Powder Temperature, M1". Ord-SIP-R5015. Artillery Div., Army Service Forces.

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